

Reduction of Interchannel Interference Noise in a Two-Channel Grating-Based OCDMA System Using a Nonlinear Optical Loop Mirror

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Abstract—We show that a nonlinear optical switch can be used to suppress the interchannel noise generated under multiuser operation within a coherent, direct-sequence optical code-division multiple-access (OCDMA) system. By incorporating a simple nonlinear optical loop mirror (NOLM) within the receiver, we demonstrate a 3.6-dB power penalty reduction in a two-channel 1.25-Gb/s 64-chip 160-Gchip/s grating-based direct-sequence OCDMA system. Even greater improvements in system performance were obtained at a data rate of 2.5 Gb/s, where the noise due to the overlap of adjacent decoded data bits also needs to be suppressed. In both instances, the system performance under two-channel operation with nonlinear filtering was shown to be comparable to that achieved under single-channel operation using the conventional matched-filter approach.

Index Terms—Gratings, optical fiber communication, optical fiber devices, optical signal processing, optical switching.

I. INTRODUCTION

OPTICAL pattern generation and recognition are likely to prove important functions in future high-capacity optical networks. These functions are required for example for header recognition in ultrafast optical time-division multiplexing (OTDM) packet-switched networks, and for use within optical code-division multiple-access (OCDMA) systems [1], [2]. OCDMA is the optical analog of the CDMA technique, applied with such success to the field of mobile communications. OCDMA is still in the very earliest stages of technological development but is attractive for a number of reasons, including the scope it offers for networks with high connectivity, more flexible bandwidth usage, asynchronous access, and improved system security.

Superstructured fiber Bragg grating (SSFBG) technology represents an attractive means to produce compact, and potentially low-cost components for a wide range of pulse processing applications, including pulse pattern generation and recognition [3], [4]. Recently, we demonstrated the suitability of SSFBGs for generating, recognizing, and recoding 64-bit-long 160-Gchip/s phase-encoded optical pulse sequences [5]. In all of our SSFBG-based optical pattern recognition experiments to date, we have relied upon the principle of simple matched filtering. Whilst good error free performance has been demonstrated, one can envisage incorporating additional nonlinear

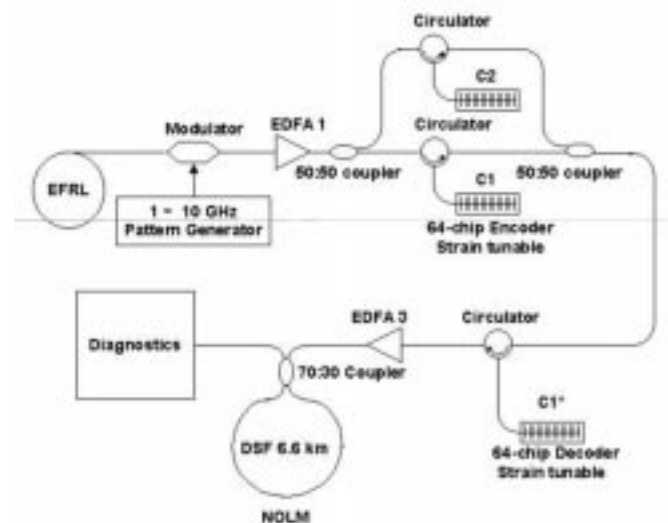


Fig. 1. Experimental setup for a two-channel 64-chip 160 Gchip/s grating-based OCDMA code : decode system.

components within SSFBG-based processing schemes to either improve the performance or to extend the functionality of this technical approach. We recently achieved the first results in this direction by incorporating a fiber-based nonlinear optical loop mirror (NOLM) in a single-channel direct-sequence OCDMA receiver, achieving error-free, penalty-free operation [4].

In this letter, we report, for the first time, the use of a nonlinear optical switch to reduce the interchannel interference noise generated under multiuser operation of an SSFBG-based OCDMA system. We demonstrate code recognition quality improvement in a two-channel 64-chip bipolar OCDMA code : decode system using a NOLM within the receiver. The nonlinear switching response of the NOLM is shown to significantly reject interference noise in regions of temporal overlap of the cross-correlation signatures of the individual coded bits, and enhances the pattern recognition contrast achievable using matched filtering alone.

II. EXPERIMENTAL SETUP AND RESULTS

Our experimental setup for assessing the performance of a multiple user access system is shown in Fig. 1. Pulses of 2.5-ps duration generated using a mode-locked soliton fiber ring laser operating at 10 GHz were first gated down to a lower repetition frequency and encoded with pseudorandom data at either 1.25 or 2.5 Gb/s. The data pulses were then split into

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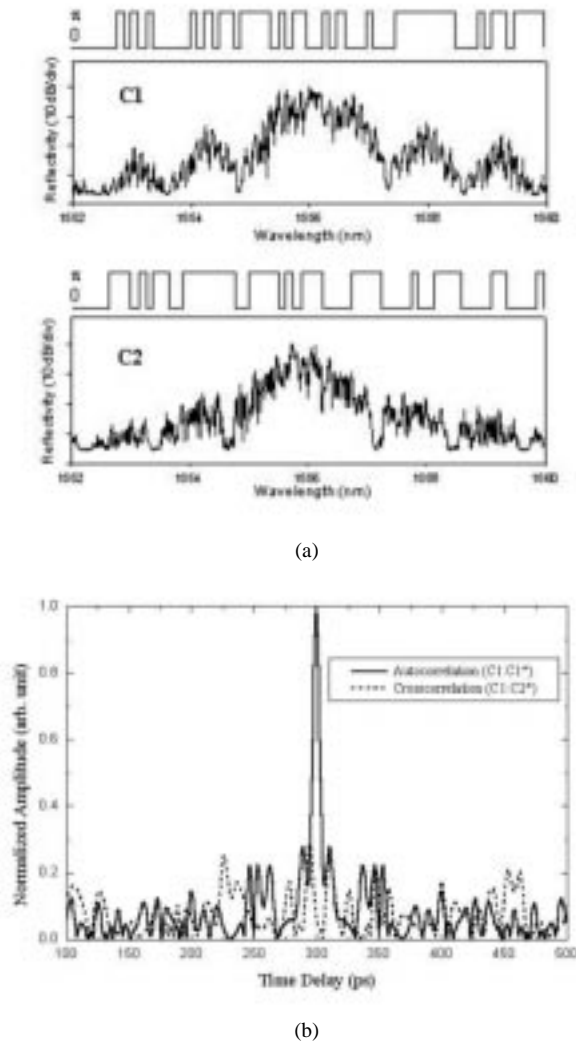


Fig. 2. (a) Spectral profile of SSFBGs for a 64-chip bipolar phase-shift-keyed gold sequence corresponding to two codes (C1 and C2) used in our experiment. (b) Theoretical waveforms of auto- (C1 : C1*) and cross-correlation (C2 : C1*) between the two codes prior to the NOLM.

coupler and fed onto two separate encoder gratings, denoted C1 and C2, respectively, before being recombined into a single fiber using a 3-dB coupler. The individual encoding SSFBGs contain phase-coding information within their refractive index profiles as defined by two separate “orthogonal” 64-bit gold codes, such that the impulse responses of the SSFBGs correspond to 64-chip phase-encoded pulse sequences. Once the data pulses are reflected from gratings C1 and C2, they generate two distinct data streams encoded with either one of the two distinct codes. Note that there was a significant difference in passage time through the system for each of the individually coded data streams so as to remove any possible correlation between the data arriving at the receiver from the two channels. Moreover, the relative passage time of the two channels could be fine-tuned to allow anywhere between no and full temporal overlap of the codes at the receiver. Fig. 2(a) shows the spectral reflectivity profile of the two 64-chip bipolar phase-shift-keyed gold sequence SSFBGs C1 and C2. These particular gratings are more fully described in [5]. The corresponding chip duration is 6.4 ps (chip rate = 160 Gchip/s). The coded data pulses

thus had a total duration of ~ 400 ps. Interchannel interference noise originates from interference between the essentially singly peaked and intense pattern recognition signature and the temporally extended, low-level cross correlation signatures associated with other codes present within the incident signal beam, which can be confirmed through a comparison of the theoretical auto- and cross-correlation traces between the two codes as shown in Fig. 2(b).

The two distinct data channels were then fed to a single decode grating (C1*) designed to provide matched filter operation to grating C1. The reflection of data pulses encoded with C1, from C1*, thus results in the formation of a short chip-length long autocorrelation pulse on a broad ~ 800 -ps-long, low-level pedestal. This short pulse can then be used to detect a code recognition signature. No such short pulse is generated when pulses encoded using C2 are reflected from the grating due to the particular properties of gold code sequences. The output from decoder grating C1* could either be detected and characterized directly or passed through a NOLM before characterization. The NOLM was made from a 70 : 30 coupler and 6.6 km of dispersion-shifted fiber (DSF), and was designed to provide both a high switching efficiency and pulse compression. The NOLM serves to remove both the low-level pedestal associated with the presence of the second channel and the finite background on the decoded pulses that are obtained by simple matched filtering, resulting in improved system performance. The soliton order inside the NOLM is $N \approx 3$ and the soliton period is 6 km (assuming a pulse of the chip duration) [6]. Erbium-doped fiber amplifiers (EDFAs) optimized for low-noise operation at 1558 nm (the operating wavelength) were incorporated within the system at appropriate positions to compensate for the loss of various elements such as the transmission line, optical circulators, and couplers. Note that in order to obtain optimal performance of the NOLM, peak power of the signal needs to be maintained. Therefore, in any practical system, if the total number of channels into the power amplifier was to be changed it would be necessary to change the average output power of the amplifier in order to maintain the optimal peak power.

We performed system tests at the data repetition rates of 1.25 and 2.5 Gb/s. The pulses in each channel were set to fully overlap temporally at the detector so as to maximize the impact of interchannel interference. As can be seen comparing the eye diagrams in Fig. 3(a) and (b), the temporal overlap of the two orthogonal codes results in severe interference noise at the receiver without the NOLM in place. However, as can be seen in Fig. 3(c), the quality of the eye opening is drastically improved by nonlinear filtering of the matched filtered signal, resulting in a substantial improvement in the bit-error-rate (BER) performance of the coding : decoding process. The measured BER plots are summarized in Fig. 4. For a data rate of 1.25 Gb/s, error-free operation with a 3.6-dB power penalty reduction relative to simple matched filtering alone was obtained through the use of the NOLM. The residual power penalty of ~ 1.6 dB is comparable to that achieved for single-channel operation without the NOLM [4]. We believe the penalty in the two-channel experiments to be due primarily to the contribution to the received average power made by imperfect suppression of the second (“orthogonal”) channel.

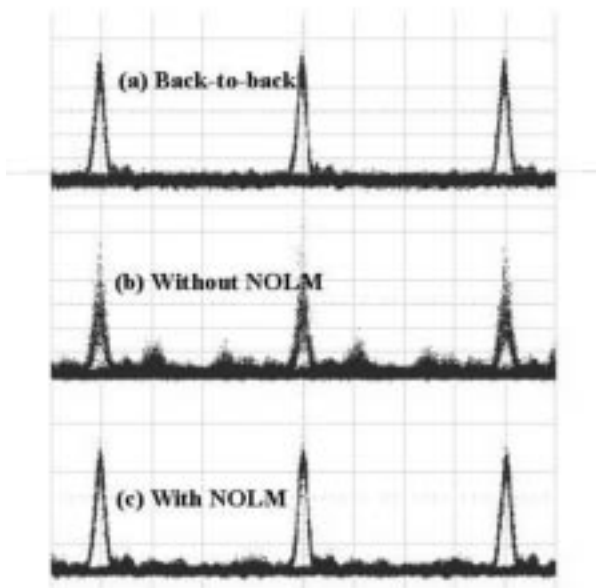


Fig. 3. Eye diagrams at 2.5 Gb/s. (a) Back-to-back, (b) after matched filtering only, (c) after self-switching by the NOLM.

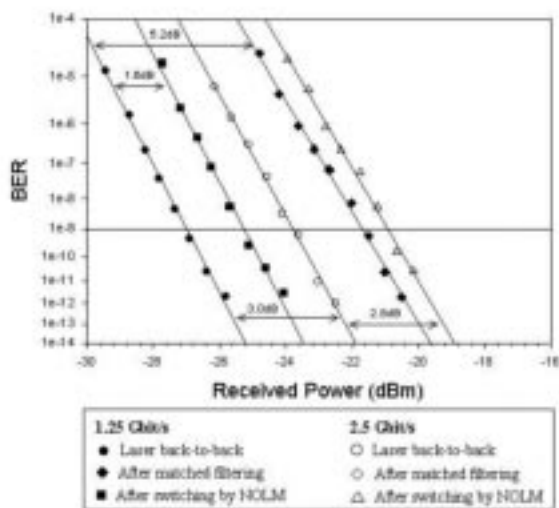


Fig. 4. BER versus received optical power for two-channel operation at 1.25 and 2.5 Gb/s.

The benefits of using the NOLM at the higher data rate of 2.5 Gb/s are even more manifest. In this instance, it was not possible to get error-free operation without the use of the NOLM. The power penalty relative to the back to back in this instance was 2.8 dB, and which again was similar to that obtained for conventional single-channel operation at this data rate. Note that at a data rate of 2.5 Gb/s, the individual pattern recognition signatures which each have a length of ~ 800 -ps overlap, providing an additional element of interference noise; hence, the slightly increased power penalty relative to the 1.25-Gb/s case in which no such overlap occurs.

Finally, in Fig. 5, we plot the results of SHG autocorrelation measurements of the pattern recognition pulse both be-

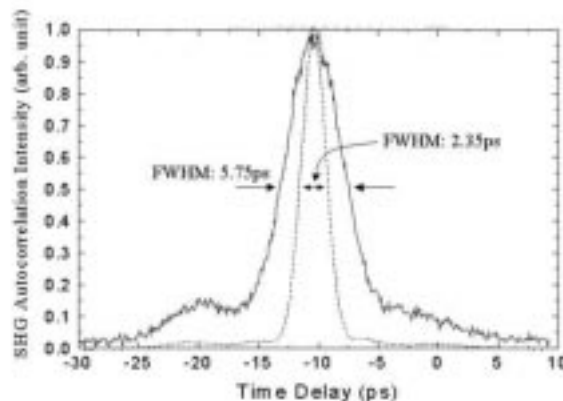


Fig. 5. SHG autocorrelation traces of the central autocorrelation spike of the decoded signal. Solid line: after matched filtering ($C1 : C1^* + C2 : C1^*$). Dashed line: after subsequent nonlinear switching by the NOLM. The data rate is 2.5 Gb/s.

fore and after self-switching by the NOLM. The pedestal rejection and pulse reshaping effects are seen to be significant. The pulsewidth after the NOLM is about the same as that of the input pulses derived from the laser, which is significant if additional reprocessing of the bit, e.g., recoding [5], is required.

III. CONCLUSION

We have experimentally demonstrated that the performance of multiuser OCDMA systems can be significantly enhanced through the addition of a simple nonlinear optical switch at the receiver to reject both interchannel and intrachannel coherence noise. Error-free performance can be more reliably obtained with a considerable power penalty reduction; moreover, cleaner, shorter pattern recognition signatures are obtained. This latter fact is important if further optical processing of the data should be required. In our experiments to date, we used a fiber-based NOLM; however, semiconductor-based nonlinear devices should offer similar system benefits.

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